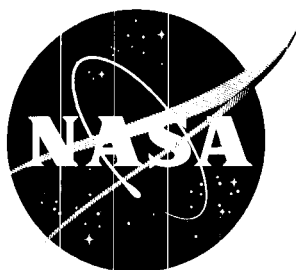NASA TM X-459

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TECHNICAL MEMORANDUM

X-459

DYNAMIC MODEL TESTS AT LOW SUBSONIC SPEEDS OF

PROJECT MERCURY CAPSULE CONFIGURATIONS WITH

AND WITHOUT DROGUE PARACHUTES

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CLASSIFICATION CH
FIED EFFECTIVE
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON   February 1961

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DYNAMIC MODEL TESTS AT LOW SUBSONIC SPEEDS OF

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SUMMARY   /8040

   An investigation has been conducted at low subsonic speeds in the
Langley 20-foot free-spinning tunnel to determine the effectiveness of
several sizes of drogue parachutes in stabilizing a Mercury capsule of
the NASA and McDonnell designs, and to determine the dynamic stability
of the capsule with and without the escape tower. In addition, tests
were made to determine the effects of high rotational rates of the cap-
sule about the symmetrical axis while in vertical descent with the drogue
parachute attached.

   Model test results indicate that in order to insure adequate stabil-
ity for the capsule descending vertically at low subsonic speeds, a stable
drogue parachute having a 6-foot diameter (laid-out-flat) would be
required. The drogue parachute is attached to the capsule with a 45-foot
(full-scale) towline at three equally spaced points around the periphery
of the antenna housing by a bridle 10 feet (full scale) in length.

   The capsule alone was very unstable in vertical descent. Large
oscillations were obtained which led to tumbling and spinning motions
with the symmetrical axis inclined to the vertical as much as 90°.
Once the spinning motion was obtained, the capsule continued spinning.
The capsule with the escape-tower end first was dynamically stable for
low angles of attack up to about 10°. For larger angles of attack, the
model was unstable and turned so that the blunt end was first. The model
then descended in a spinning motion at an angle of attack of approximately
45°.

   The antenna housing can be used as an emergency means of pulling the
main parachute out.

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[*]Title, Unclassified.

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INTRODUCTION

As part of an overall program in support of Project Mercury, an investigation utilizing dynamically scaled models has been conducted in the Langley 20-foot free-spinning tunnel and at an outdoor test facility at low subsonic speeds to determine primarily the effectiveness of several sizes of drogue parachutes in stabilizing two proposed Mercury capsule configurations while in vertical descent. A drogue parachute has been considered for deployment in the Mercury flight program after reentry at an altitude of approximately 60,000 feet and at a Mach number of approximately 1. The primary function of the drogue parachute will be to stabilize the capsule in vertical descent and to drag the main parachute out at an altitude of approximately 10,000 feet for final descent and landing of the capsule.

The present investigation includes tests of drogue-parachute stabilized models at simulated test altitudes from sea level to 35,000 feet. The dynamic stability characteristics of the capsule in free descent at low speeds with and without an escape tower were also investigated. A few tests were conducted to determine the effectiveness of a proposed emergency system for pulling the main parachute out in case of a failure in the drogue-parachute system. The emergency system consisted of ejecting the antenna housing, which in turn served as a drogue to pull out the main parachute. As stated previously, a few tests on large models dropped from a helicopter were also made at an outdoor test facility to determine the effect of Reynolds number.

SYMBOLS

d   maximum body diameter, ft

α angle of attack of model center line, deg

ω rate of rotation about the model symmetrical body axis, rps

Ω rate of rotation of model about vertical spin axis, rps

m   mass, W/g, slugs

W   weight, lb

g   acceleration due to gravity, 32.17 ft/sec^2

ρ air density, slugs/cu ft

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A   maximum cross-sectional area at maximum diameter, sq ft

μ relative density, $m/\rho Ad$

I_X, I_Y, I_Z moments of inertia about X-, Y-, Z-body axes, respectively,
                  slug-ft^2

x_{cg} distance of center of gravity rearward of maximum diam-
                  eter, in.

APPARATUS

The model tests were conducted primarily in the Langley 20-foot
free-spinning tunnel. The tunnel is an atmospheric wind tunnel with a
maximum air speed of about 95 feet per second.

MODELS

The models used in the vertical-tunnel investigation represented
both the NASA and the McDonnell proposed designs of the capsule and were
constructed of plastic and fiber glass. The models used in the helicop-
ter drop tests represented only the NASA design. A drawing of the cap-
sules and their dimensional characteristics is presented in figure 1.
The models tested in the vertical tunnel were 1/10 and 1/6.44 scale and
were dynamically ballasted for simulated test altitudes of sea level and
35,000 feet, respectively. The antenna housing was dynamically ballasted
separately for the tests in which it was used to pull out the main chute.
For the helicopter drop tests, the models were 1/4 scale and were bal-
lasted for sea level and 20,000 feet. The mass and inertia characteris-
tics for the proposed capsules and the antenna housing tested are pre-
sented in table I. The parachutes used were generally stable, flat,
circular type constructed of 400-porosity material. Porosity is defined
as the volume of air in cubic feet that will flow through 1 square foot
of cloth in 1 minute at a pressure of one-half inch of water. The
parachutes were attached to the capsules by 45-foot (full-scale) towlines.
Two towline-attachment configurations were used on the capsule as shown
in figure 2. For the single-towline configuration, the towline was
attached to the center of the canister top. For the three-point-attachment
configuration, 35 feet of the towline was a single line and 10 feet was
a triple line. The three lines, hereinafter referred to as a bridle,
were attached to three equally spaced points around the periphery of the
antenna housing. (See fig. 2.) For some of the tests, a swivel was used
at the juncture of the single line and bridle. A dimensionally scaled

model of a FIST ribbon design parachute was used for a portion of the
tests. A 1/10-scale model of the escape-tower configuration as tested
is shown in figure 3.

TEST PROCEDURE

The general test procedure used in the vertical tunnel is described
in reference 1. For this investigation, the capsule model was launched
into the vertically rising airstream by hand. The Reynolds number for
these tests ranged from approximately 230,000 to 360,000 based on the
maximum diameter. For tests to determine the stability in descent of
the capsule with the drogue parachute, the capsule was launched into
the tunnel with the drogue parachute open. For tests to determine the
effectiveness of the drogue parachute in recovering the capsule from
spinning or tumbling motions, the capsule was launched with the drogue
parachute packed, and at the desired time, the drogue parachute was
deployed by means of a remotely controlled mechanism. In order to
determine the effectiveness of the antenna housing in pulling out the
main parachute, the main parachute was packed tightly in the model to
obtain high resistance forces and loosely to obtain relatively low
resistance forces. The forces were measured by a static load attached
to the main parachute before the free-falling dynamic tests were made.

For the outdoor tests, models were released from the helicopter at
altitudes of 3,000 and 5,000 feet and were allowed to fall freely for
some time to allow them to develop various possible motions. The Reynolds
number for these tests was approximately 1,000,000 based on the maximum
diameter. All tests were photographed with 16-millimeter film at about
64 frames per second.

TESTS

Dynamic model tests were conducted on the capsule models of the
two proposed designs to determine the dynamic stability characteristics
of the capsules with and without drogue parachutes and with the escape
tower. Tests were also conducted to determine the effectiveness of the
drogue parachute in recovering the capsule from spinning and tumbling
motions. Several size parachutes were used in the investigation to deter-
mine their effectiveness in stabilizing the capsule. Tests were also
conducted to determine the effects of rotation about the capsule symmet-
rical axis. Vanes were employed to promote the rotation and were located
at the maximum diameter.

In the event that the drogue parachute fails to deploy, the antenna-housing section of the capsule (see fig. 1) will be deployed as an emergency system to pull out the main parachute. The effectiveness of the antenna housing in pulling out the main parachute was tested for two towline lengths (29 and 2 feet).

RESULTS

Model test results of both the NASA and McDonnell designs of Project Mercury capsules are presented in figures 4 to 8, and a motion-picture film supplement has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper, on the page immediately preceding the abstract and index pages.

Initial tests on the NASA and McDonnell designs indicated that test results from both designs were very similar; therefore, the latest capsule configuration, which is the McDonnell design, was used for most of the tests. Brief tests indicated that drogue parachutes smaller than 6 feet in diameter (full scale) indicated poor stabilizing characteristics and parachutes larger than 8 feet in diameter (full scale) indicated such a small increase in stabilization that larger parachutes were not considered. Therefore, most of the test results presented in this report are for the 6- and 8-foot drogue parachutes.

Typical test results of the capsule alone are presented in figure 4. The effectiveness in stabilizing the capsule with the 6- and 8-foot drogue parachutes with the single towline attachment is shown in figure 5. The stabilizing effectiveness of the 6- and 8-foot drogue parachutes with the three-point-attachment configuration is shown in figure 6. In figure 7 is given the effects of altitude on the stability of the capsule with the drogue parachute. In figure 8 is shown film strips of the drop tests of the escape-tower configuration in the vertical tunnel.

DISCUSSION

Dynamic Stability of the Capsule Alone

Model test results of the capsules alone indicated that the capsules were very unstable at subsonic speeds for all center-of-gravity positions tested (fig. 4). The capsules oscillated, tumbled, and entered spinning motions; the symmetrical axis was inclined from the vertical as much as 90° for some of the spinning motions, and in these instances the spin persisted. The other motions were of an intermediate nature. Model test results indicate that, for the center-of-gravity positions tested, center-of-gravity change had no appreciable effect on the motion of the capsule.

Drogue-Parachute Stabilized Model

The results of tests conducted to determine the effectiveness of the
6- and 8-foot drogue parachutes in stabilizing the capsule are presented
in figures 5 to 7. Changes in center-of-gravity position had no appreci-
able effect on the motions of the capsule with the drogue parachute for
the center-of-gravity positions tested.

The relative effectiveness of the 6- and 8-foot drogue parachute with
the single towline attachment is shown in figure 5. Oscillations of the
capsule with the 6-foot drogue parachute attached were as high as $\pm 60^{\circ}$
whereas oscillations only ranged up to about $\pm 20^{\circ}$ with the 8-foot drogue
parachute; the period of oscillation in both cases was about 1.5 seconds.
Thus, the 8-foot parachute showed a marked improvement over the 6-foot
parachute when the single-towline-attachment configuration was used. In
an effort to decrease the oscillations further, 10 feet of the single tow-
line was replaced by a bridle (three lines) and attached to three equally
spaced points around the periphery of the antenna housing. (See fig. 2.)
The test results (fig. 6) indicated that the three-point-attachment con-
figuration was considerably more effective than the single-point-attachment
configuration for both the 6- and 8-foot parachutes. Maximum oscillations
measured on the capsule with the 6-foot parachute were about $\pm 20^{\circ}$ and with
the 8-foot parachute were about $\pm 8^{\circ}$. An analytical investigation (ref. 2)
indicated that, by attaching the towline at several points around the
periphery of the antenna housing, the damping-in-pitch coefficient C_{m_q}
of the system is increased; therefore, the amplitude of the oscillation
is decreased. For the 6-foot parachute, use of the three-point attach-
ment decreased the capsule oscillations to within $\pm 10^{\circ}$. Test results
indicate that the effectiveness of the drogue parachute in stabilizing
the capsule diminished somewhat with increasing altitude when the single-
towline-attachment configuration was used (not presented in figures).
However, the three-point-attachment configuration caused little or no
difference in the stability of the capsule with the drogue parachute
between the simulated test altitudes of sea level and 35,000 feet. The
results obtained with the 6-foot parachute at sea level and at 35,000 feet
are presented in figure 7.

Effect of Rotation About the Capsule Symmetrical Axis

Tests were conducted to determine the effects of rotation about the
symmetrical axis for the capsule with the drogue parachute in vertical
descent. Both the single and the bridle attachments were tested. The
effect of a swivel was also determined in the bridle configuration.
Large vanes were employed to promote rotation and were mounted on the
capsule at the maximum diameter. The rotation was intended to give some
insight in regard to possible effects of protuberances on the full-scale

capsule. For the single-towline-attachment configuration, the capsule pitched up to about 90° as the rotational rate became high (about 3 rps, full scale) and precessed about the towline attachment point. With the bridle-attachment configuration, the pitch-up of the capsule was greatly delayed. When, however, the three lines of the bridle became interwoven due to rotation (effectively, a single towline), the capsule again pitched up to approximately 90°. Use of a swivel prevented this later pitch-up.

Escape-Tower Configuration

Tests on the escape-tower configuration (fig. 3) were made at a simulated test altitude of sea level for the condition after rocket burn-out. (Weight and center-of-gravity positions of the escape-tower configuration are given in table I.) The model was dropped with tower end first into the vertically rising airstream to determine the dynamic stability for various angles of attack. Test results indicate that the configuration with the tower end first is dynamically stable when launched at angles of attack up to approximately 10°. Models launched at angles of attack higher than 10° diverged and descended with the blunt end first at an angle of attack of about 45°. Film strips showing a stable and an unstable test model are shown in figure 8. The model at first is shown (fig. 8(a)) being launched at an angle of attack of 6°. For this angle of attack, the model is stable and continues to drop with the tower end first to the bottom net in the tunnel test section. In figure 8(b), the model is launched at an angle of attack of 12°. The model diverges and turns so that the blunt end is first.

Alternate Parachute Deployment System

Tests were conducted to determine the effectiveness of the antenna housing in pulling out the main parachute in case the drogue parachute fails to deploy. The housing was deployed while the capsule was descending freely in the vertical wind tunnel; thus, the dynamic effect of sudden application of the drag of the antenna housing is obtained. Test altitude was simulated at sea level. Two towline lengths (29 and 2 feet, full scale) between the antenna housing and the parachute were tested. These lengths were used since they were being considered for Project Mercury.

The model results obtained with the 29-foot towline indicated that, for resistance forces of 1,000 to 1,200 pounds (full scale), the antenna housing did not always provide sufficient drag to deploy the parachute. When the force was reduced to 200 to 400 pounds (full scale), the parachute came out in every case. With a 2-foot towline (full scale), the parachute again came out in every attempt for the 200- to 400-pound required force; however, the time required to deploy the parachute

increased, compared to that required when the 29-foot towline was used.
With the 2-foot towline, the antenna housing is held mostly in the near-
dead-air region when trailing so close behind the capsule and, therefore,
bounces around considerably before the parachute is pulled out. Photo-
graphs of these tests are shown in the film supplement.

Reynolds Number Effects

In general, the results obtained for the drop tests at a higher
Reynolds number (approximately 1,000,000 based on the maximum diameter)
agreed well with those obtained in the vertical tunnel at a low Reynolds
number (approximately 230,000 based on the maximum diameter). In addition,
the results of the force tests conducted on the capsule for a Reynolds
number range of 340,000 to 4,850,000 (based on the maximum diameter) indi-
cated little or no effect on the forces and moments due to Reynolds number
(ref. 3). The results of the tests on the small-scale model obtained in
the vertical wind tunnel are, therefore, considered to be indicative of
the motions that might be obtained on the full-scale capsule.

SUMMARY OF RESULTS

The results of an investigation on models of Project Mercury capsules
are as follows:

1. The capsule in free descent at low subsonic speeds was very
unstable. The capsule oscillated, tumbled, and entered spinning motions;
the symmetrical axis inclined from the vertical as much as 90°.

2. A stable drogue parachute having a 6-foot diameter can insure
adequate stability for the capsule descending vertically at low subsonic
speeds provided the parachute towline is attached at three equally spaced
points around the periphery of the antenna housing.

3. The 8-foot drogue parachute stabilized the capsule much better
than the 6-foot parachute when a single towline attachment was used.
The capsule oscillated up to $\pm 20^\circ$ with the 8-foot parachute attached and
up to $\pm 60^\circ$ with the 6-foot parachute attached.

4. A bridle attached at three points equally spaced around the periph-
ery of the antenna housing improved the stability of the capsule consider-
ably for both the 6- and 8-foot parachutes. Maximum oscillations measured
on the capsule with the 6-foot parachute were about $\pm 20^\circ$ and with the
8-foot parachute were about $\pm 8^\circ$.

5. High rotational rates about the capsule symmetrical axis (3 rps, full scale) caused the capsule to pitch up to approximately 90° and precess about the single towline attachment. With a bridle (three lines), pitch-up was delayed until the three lines became interwoven; a swivel eliminated this later pitch-up.

6. The capsule with escape tower maintained directional stability with tower end first when launched at angles of attack up to approximately 10°. For angles of attack higher than 10°, the capsule-tower configuration turns so that the blunt end is first and descends in a spinning motion at an angle of attack of approximately 45°.

7. In case of a failure of the drogue parachute, the antenna housing with a 2-foot towline, will provide sufficient force to pull the main parachute out if the required force is not over 400 pounds. For forces larger than 400 pounds, a longer towline would be required.

Langley Research Center,
    National Aeronautics and Space Administration,
        Langley Field, Va., November 28, 1960.

REFERENCES

1. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning
    Wind Tunnel. NACA Rep. 557, 1936.

2. Lichtenstein, Jacob H.: Analytical Investigation of the Dynamic
    Behavior of a Nonlifting Manned Reentry Vehicle. NASA TN D-416, 1960.

3. Johnson, Joseph L., Jr.: Wind-Tunnel Investigation at Low Subsonic
    Speeds of the Static and Oscillatory Stability Characteristics of
    Models of Several Space Capsule Configurations. NASA TM X-285, 1960.

TABLE I.- MASS AND INERTIA CHARACTERISTICS FOR LOADINGS TESTED

ON THE PROJECT MERCURY CAPSULE DESIGNS

[Values given are full scale]

Configuration	Weight, lb	Center of gravity rearward of maximum diameter, $\frac{x_{cg}}{d}$, percent	Relative density, μ at -		Moments of inertia, slug-ft² (a)		
			Sea level	35,000 feet	I_X	I_Y	I_Z
Full-scale configuration							
Capsule, NASA design	2,150	24.6	121	390	253	434	434
Capsule, McDonnell design	2,170	22.6	151	488	279	442	430
Capsule, McDonnell design	2,170	29.9	151	488	279	442	430
Escape-tower configuration, McDonnell design	2,755	87.2	192	620	244	4,555	4,566
Antenna housing, McDonnell design	83	129.2	---	---	---	---	-----
Dynamic model							
Capsule, NASA design	2,213	24.5	124	402	267	497	497
Capsule, McDonnell design	2,170	22.6	151	488	279	447	447
Capsule, McDonnell design	2,170	29.3	151	488	225	446	446
Escape-tower configuration, McDonnell design	2,742	87.6	191	617	235	4,270	4,270
Antenna housing, McDonnell design	81	129.2	---	---	---	-----	-----

a Moments of inertia are given about the center of gravity.
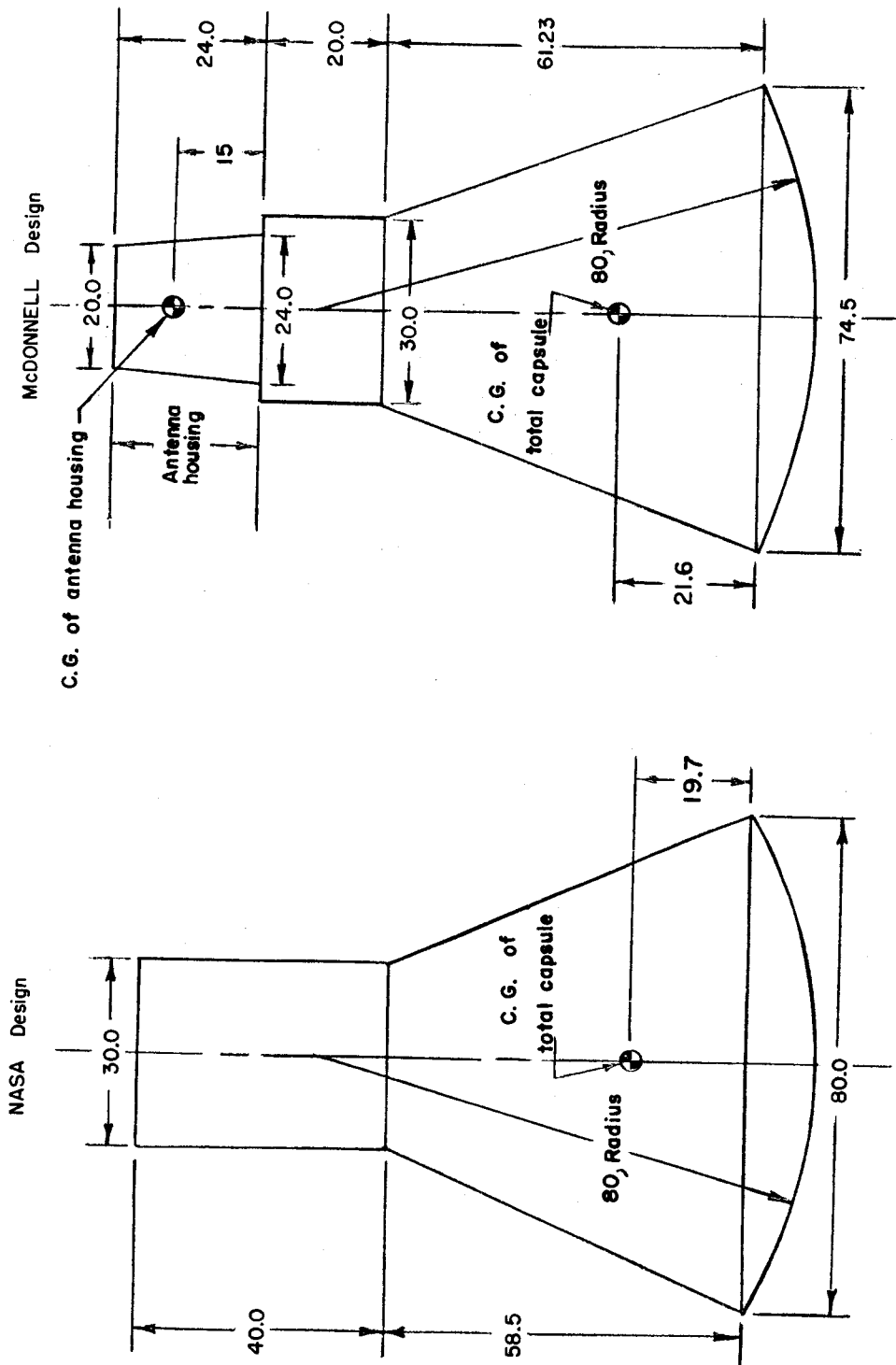
Figure 1.- Drawing of the NASA and McDonnell designs of Project Mercury capsules as tested in the Langley 20-foot free-spinning tunnel. All dimensions given are full scale and in inches. Center of gravity shown is 24.6 percent rearward of maximum diameter for the NASA design and 29.9 percent, for the McDonnell design.

Three-point attachment

35

10

Location of swivel
when used

Three-line bridle

120°

Antenna-housing top
showing attachment points

Single-point attachment

45
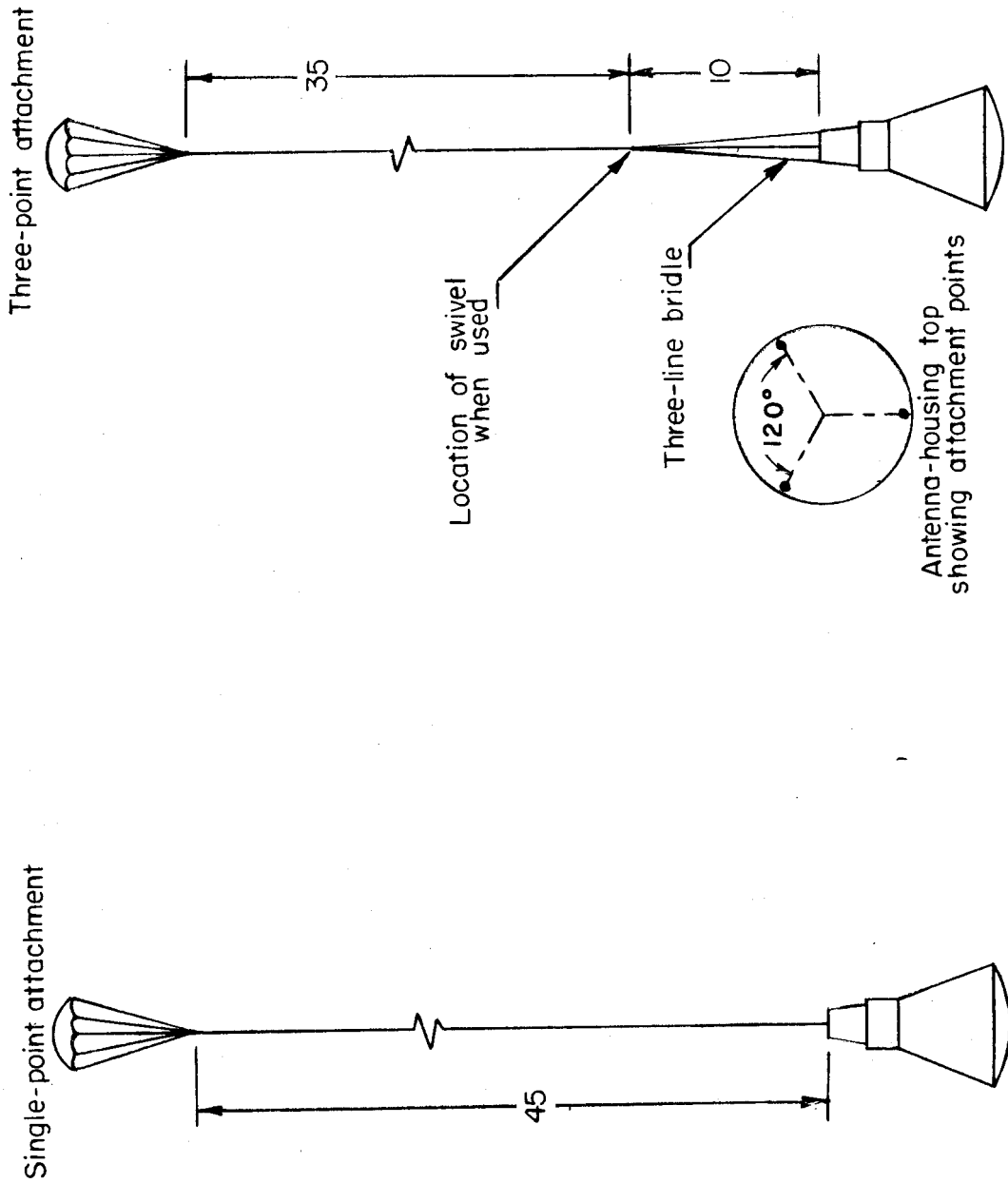
Figure 2.- Drogue parachute showing towline attachments. Dimensions are full scale and in feet.
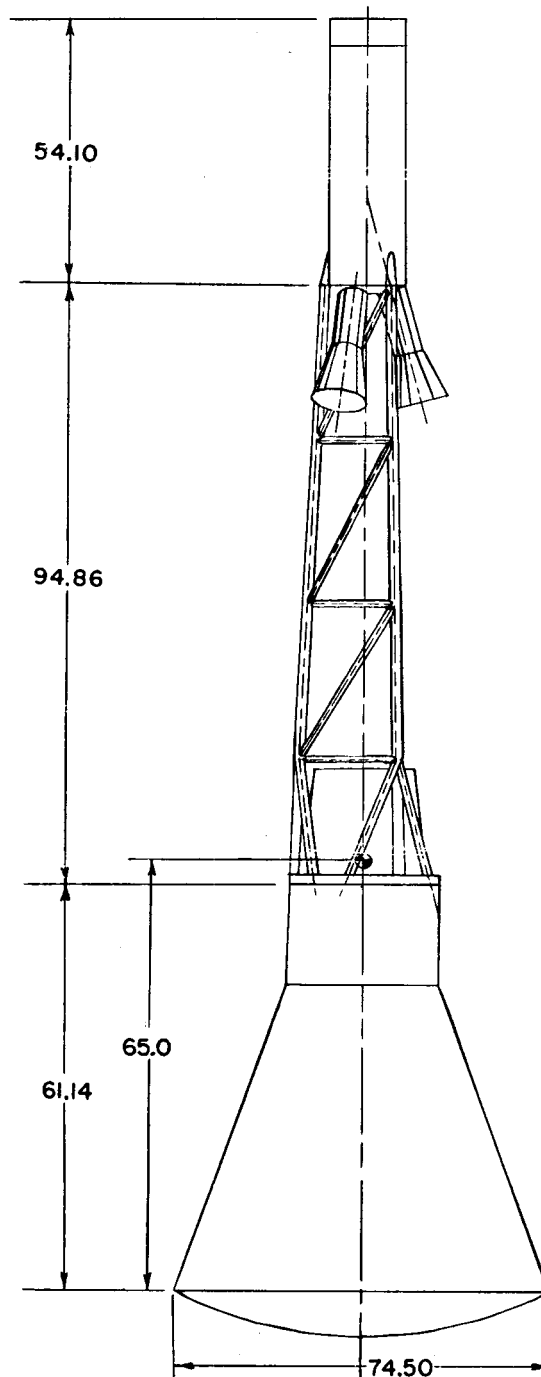
Figure 3.- A 1/10-scale model of the escape-tower configuration of Project Mercury capsule as tested in the Langley 20-foot free-spinning tunnel. Dimensions are full scale and in inches.

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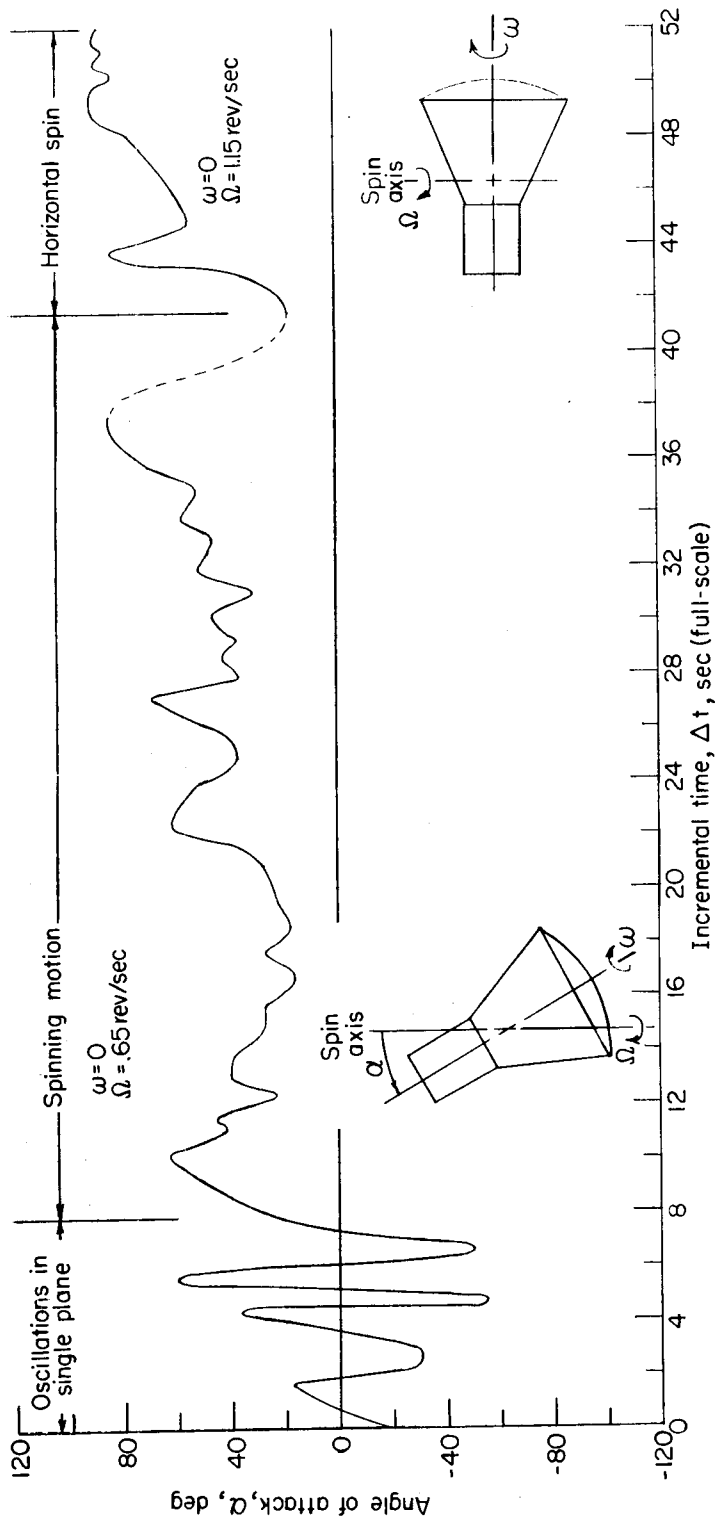
(a) NASA capsule design; cg = 24.6 percent.

Figure 4.- Free-falling tests of a 1/10-scale dynamic model of the Project Mercury capsule in the Langley 20-foot free-spinning tunnel. Simulated test altitude, sea level.
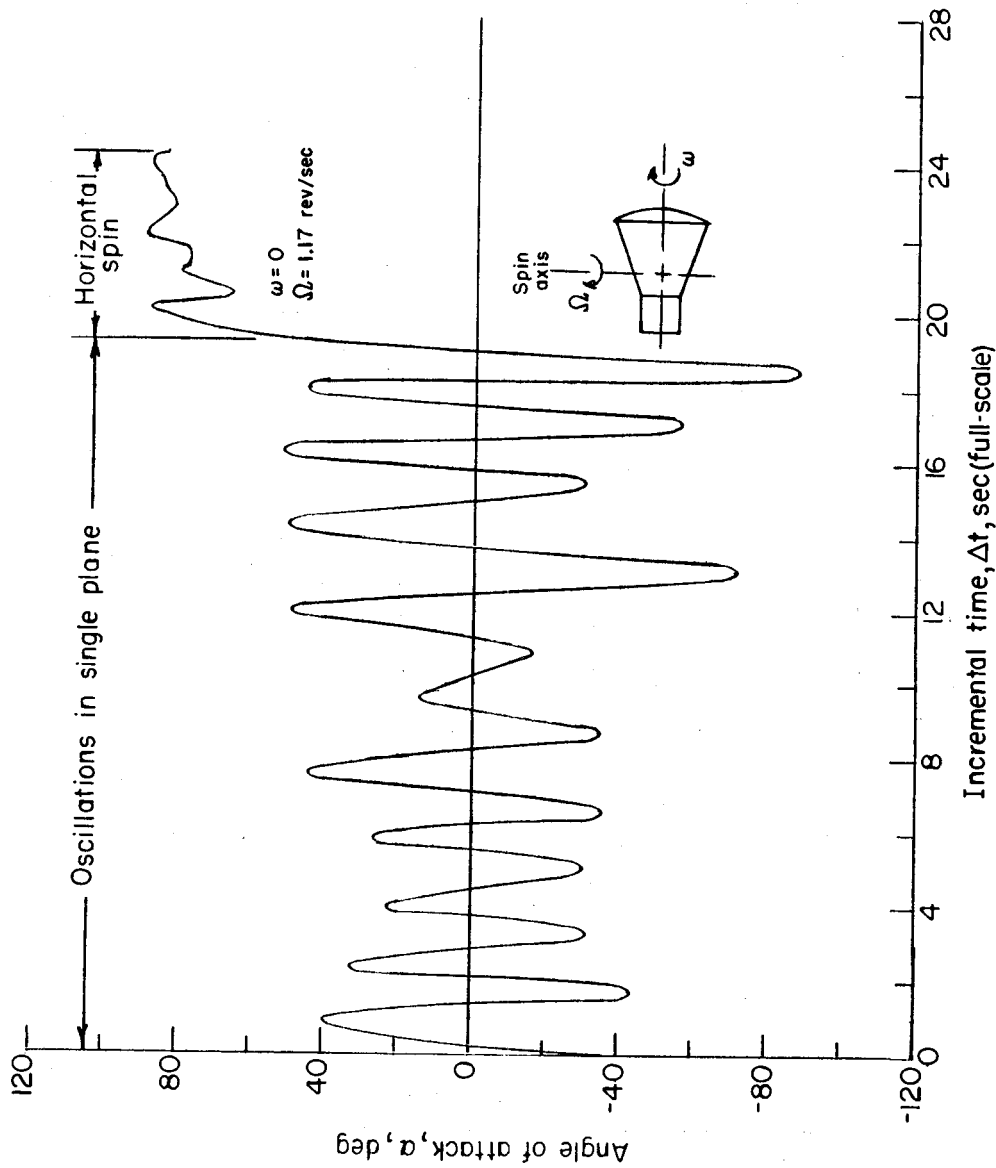
(b) McDonnell capsule design; cg = 22.6 percent.

Figure 4.- Continued.
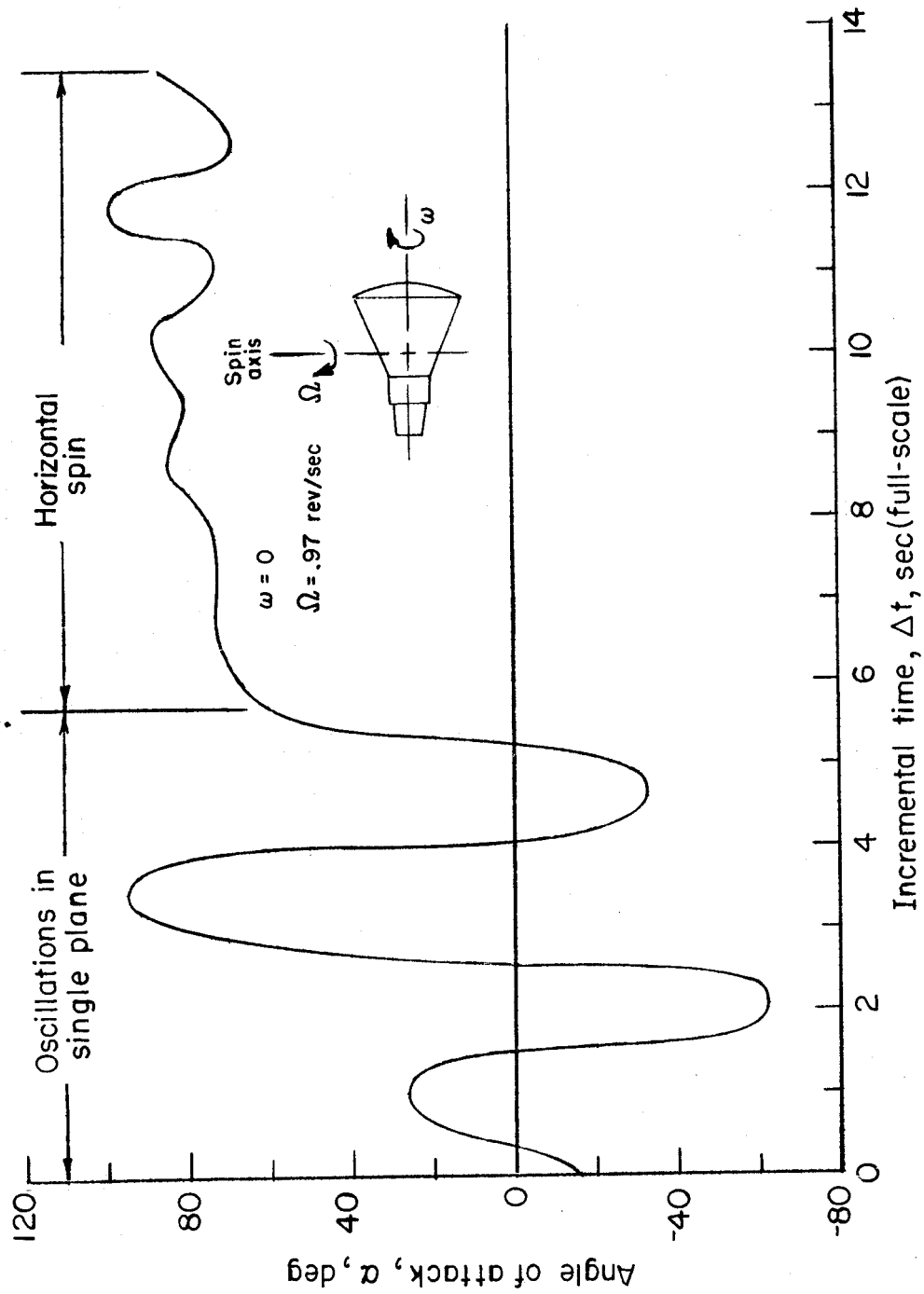
(c) McDonnell capsule design; cg = 29.3 percent.

Figure 4.- Concluded.

Figure 5.- Effect of parachute size for the single-towline-attachment configuration. Simulated test altitude, sea level; NASA capsule design; cg = 24.6 percent.
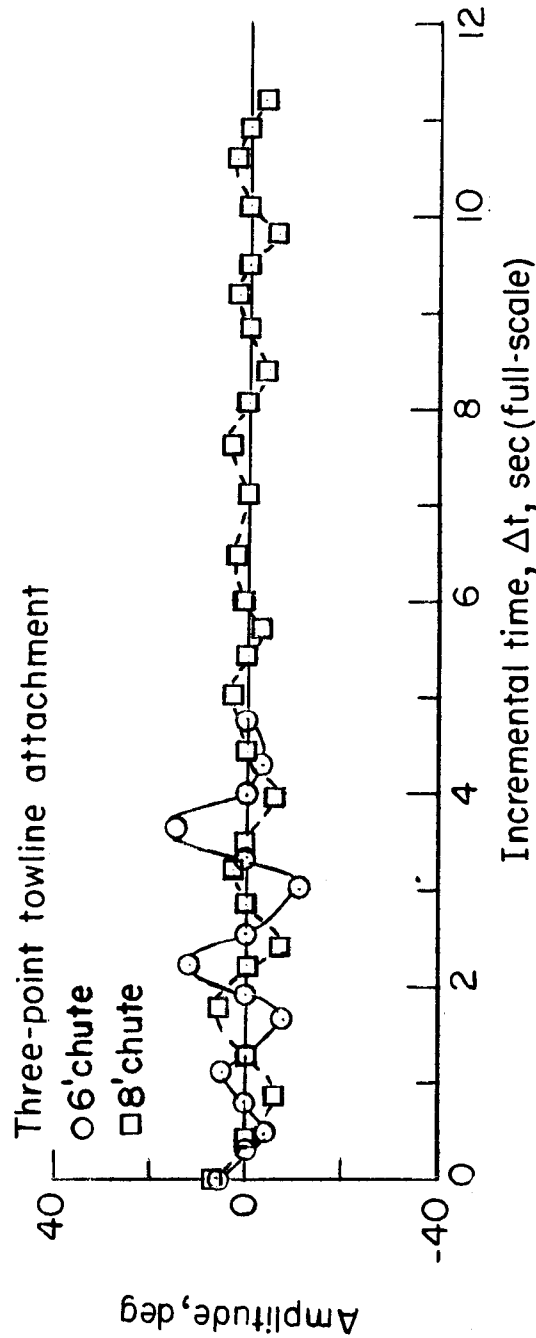
18   CONFIDENTIAL

Figure 6.- Effect of parachute size for the three-point-attachment configuration. Simulated test altitude, sea level; McDonnell capsule design; cg = 22.6 percent.
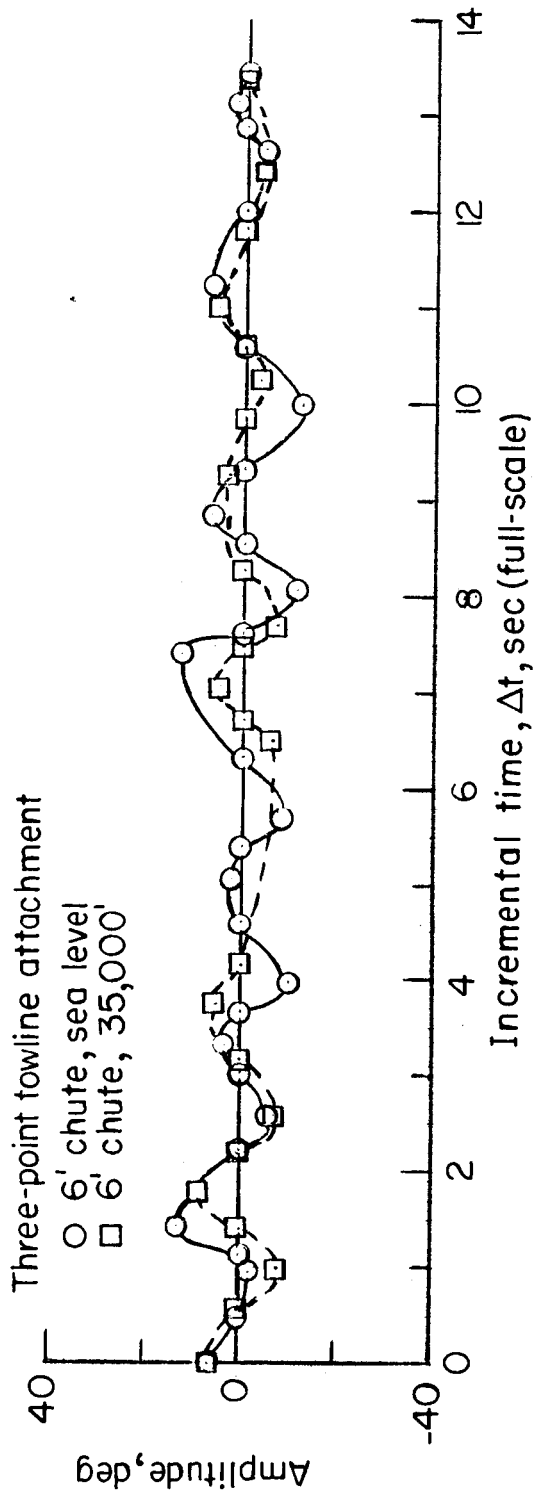
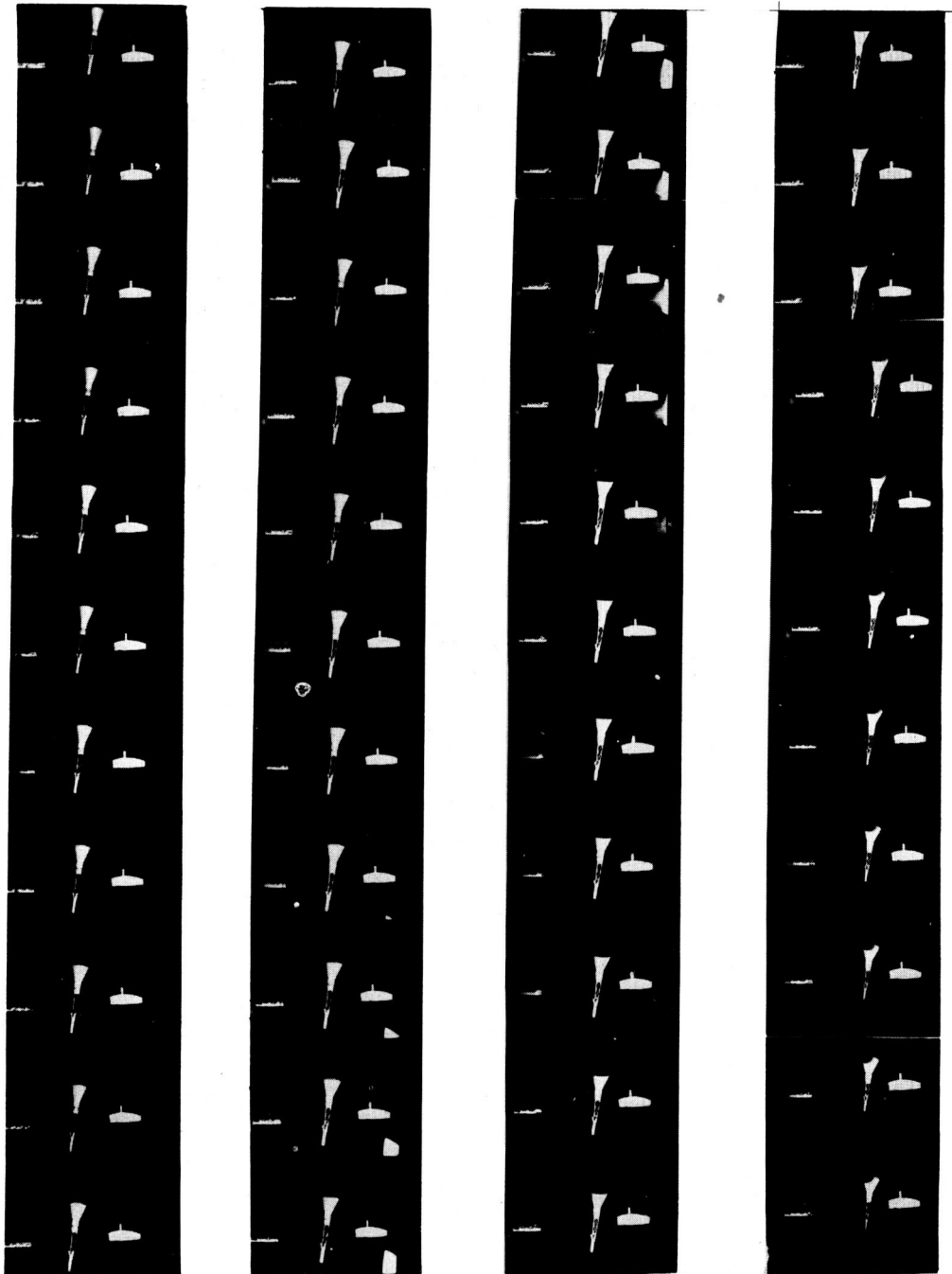Figure 7.- Effect of altitude for the 6-foot drogue parachute with the three-point-attachment configuration. McDonnell capsule design; cg = 29.3 percent.

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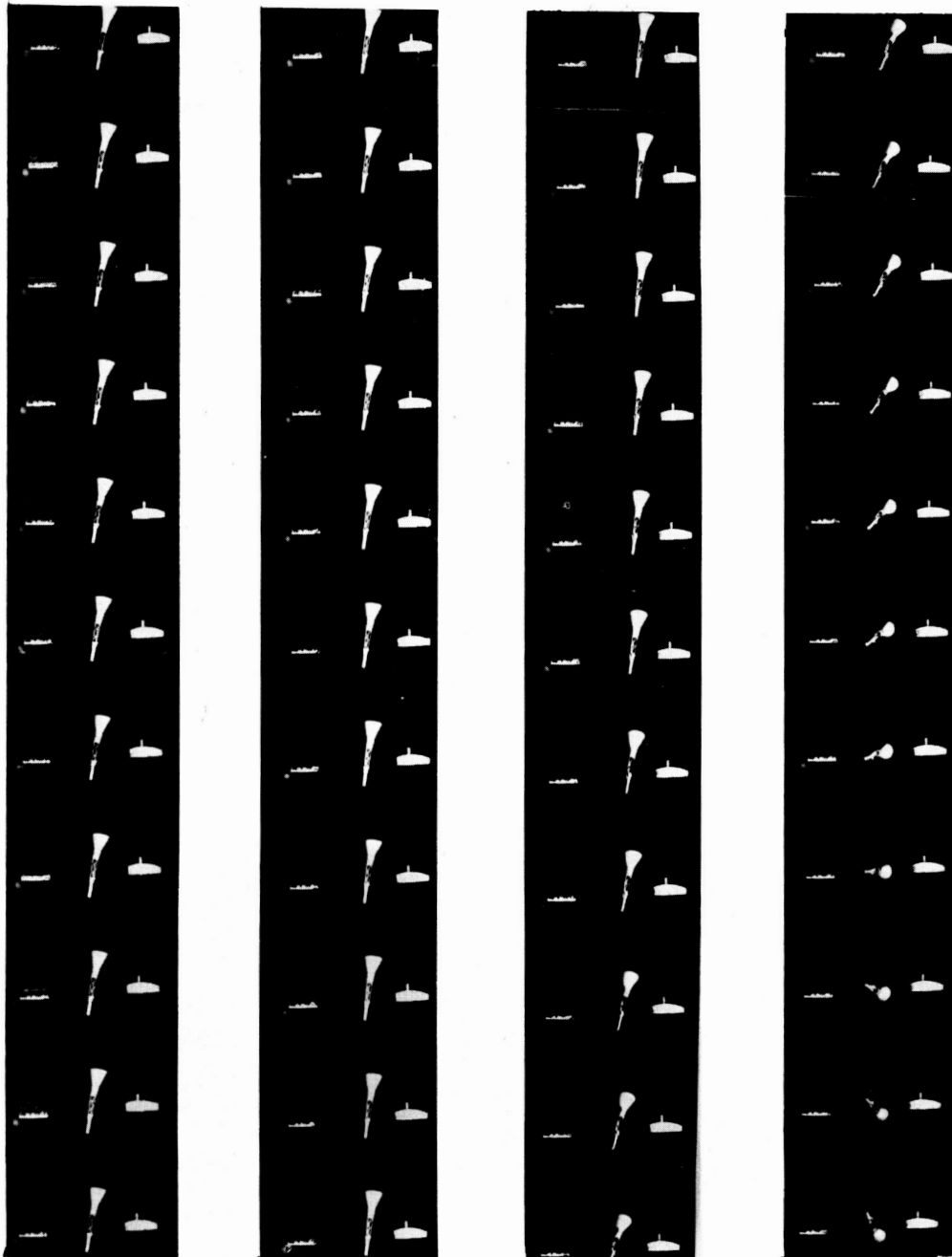(a) Launched at an angle of attack of 6°; stable. L-60-6909

Figure 8.- Dynamic 1/10-scale model of escape-tower configuration launched into vertical rising airstream.

L-60-6910

(b) Launched at an angle of attack of 12°; unstable.

Figure 8.- Concluded.

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A motion-picture film supplement, carrying the same classification as the report, is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The film (16 mm, 7 min 50 sec, B&W, silent) shows tests in the Langley 20-foot free-spinning tunnel of a Project Mercury capsule with and without a drogue parachute.

Requests for the film should be addressed to the

      National Aeronautics and Space Administration
      Office of Technical Information and Educational Programs
      Technical Information Division (Code ETV)
      Washington 25, D.C.

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